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RESEARCH MEMORANDUM

SPARK IGNITION OF FLOWING GASES

III - EFFECT OF TURBULENCE PROMOTER ON ENERGY REQUIRED TO IGNITE A PROPANE-AIR MIXTURE

By Clyde C. Swett, Jr., and Richard H. Donlon

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Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE
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SUMMARY

An investigation was conducted to determine the effect of turbulence generated by different sizes of wire grid on the minimum spark-ignition energy of a flowing propane-air mixture. Test conditions were: pressure, 5 inches of mercury absolute; temperature, 80° F; fuel-air ratio, 0.0835 (by weight); velocity, 50 to 250 feet per second; spark duration, 500 microseconds; and electrode spacing, 0.37 inch. The wire sizes of the turbulence promoters ranged from 0.006 to 0.105 inch in diameter and the promoters were located either $4\frac{3}{8}$ or $6\frac{3}{8}$ inches upstream of the spark electrodes. The investigation was conducted with turbulence having superimposed flow pulsations and duct resonance.

The required ignition energy increased with wire size of the turbulence promoter and with gas velocity and decreased with distance from the promoter to the spark electrodes. The required ignition energy therefore increased with those factors that are reported to generate increased intensity of turbulence. At a velocity of 250 feet per second, three times more energy was required with the 0.105-inch wire-diameter promoter than with no promoter.

INTRODUCTION

In order to provide information for the design and operation of jet-engine combustors, research is being conducted at the NACA Lewis laboratory to study the fundamental variables affecting ignition and combustion of fuel-air mixtures. As part of this research, the parameters which may influence the energy required for a spark to ignite homogeneous fuel-air mixtures are being investigated.

Previous studies (references 1 and 2) have shown the effect on ignition energy of three gas parameters: mixture pressure, velocity, and fuel-air ratio; and four spark parameters: spark duration, electrode spacing, electrode configuration, and electrode material. One additional gas parameter which has not been treated in the literature up to the present time is gas-stream turbulence. It has been considered possible that turbulence may account for a portion of the large ignition energy required in a spark for altitude ignition of jet-engine combustors. Increasing the intensity or the scale of turbulence, or both, would increase the rate of eddy diffusion. The eddy diffusion coefficient could become equal to or greater than the molecular diffusion coefficient. Thus, the presence of turbulence might result in the ignition energy being dissipated over a much larger volume. The larger volume might therefore require an increased initial energy in order to obtain ignition. A study of the relation between ignition energy and turbulence should be of value in understanding the mechanism of spark ignition.

The objective of the present research was the determination of effects of turbulence on the energy required to ignite a flowing homogeneous mixture of propane and air. Various types of screen were inserted in the ignition apparatus upstream of the spark electrodes to vary the intensity and scale of turbulence at the electrodes. The mixture fuel-air ratio was maintained constant at 0.0835, the pressure at 5 inches of mercury absolute, the temperature at 80° F, the spark duration at 500 microseconds, and the electrode spacing at 0.37 inch.

APPARATUS AND PROCEDURE

The apparatus used for determining the effect of turbulence promoters on spark-ignition energy is shown in figure 1. An exhaust system that was maintained at an absolute pressure of 2.5 inches of mercury was used to draw room air (temperature, 80° F) through the apparatus. The air, after being metered at the orifice, was passed through the flow-control valves, inlet diffuser, calming section, nozzle, turbulence promoter, test section, exit diffuser, flame arrester, and sonic choke. Propane, metered by rotameters, was injected into the 4-inch-diameter pipe. The inlet diffuser was designed to form a transition between the 4-inch pipe and the 14-inch-square calming section. The calming section contained five 50-mesh screens spaced 2 inches apart to eliminate approach-stream turbulence. A removable plate, in which various turbulence promoters could be installed, was located at the entrance of the test section. The promoters were wire screens having wire diameters of 0.006, 0.045, and 0.105 inch and mesh-to-diameter ratios of 5. The spark electrodes were installed in the test section at a distance $4\frac{3}{8}$ or $6\frac{3}{8}$ inches downstream from the turbulence promoter. Windows were provided in the test section and in the exit diffuser for observation of the spark and of the flame downstream, which was the criterion for ignition. A flame arrester consisting of a series of fine-mesh screens prevented explosions from occurring in the exhaust facility. The purpose of the sonic choke was to prevent exhauster pulsations from traveling upstream into the test section. The choke was used to set the operating pressure at 5 inches of mercury absolute in the test section.

The ignition and the energy-measuring systems used are described in reference 2. The ignition system produced a single spark having a duration of approximately 500 microseconds and an exponential decay of current. Oscillographic techniques were utilized in the energy-measuring system. The electrodes used were shanks from number 74 high-speed drills (0.02250 in. in diameter) and were located on the same center line perpendicular to the direction of flow. The electrode spacing was 0.37 inch, which is the quenching distance for the particular pressure and fuel-air ratio used (reference 3). New electrodes gave rapid arc-to-glow transitions, which resulted in oscillograms that were difficult to read. After installing new electrodes, it was therefore necessary to condition them by running an ignition test at low velocity so that they were bathed in flame for a short time. Such treatment apparently changed the emission characteristics of the electrodes and resulted in comparatively smooth oscillogram traces.

The procedure for the ignition tests was as follows: The proper flow conditions of fuel and air were established to give a fuel-air ratio of 0.0835 by weight. A switch was then operated to cut off the fuel flow and start a timing circuit. After a delay period that could be varied as desired, depending upon the flow conditions, the timing circuit closed the ignition switch and a spark occurred. Fuel shut-off before ignition prevented large amounts of fuel from being burned in the apparatus and reduced damage due to burning of the fine-mesh calming screens, promoter screens, and electrodes. Precautions were taken to insure the occurrence of ignition soon enough after fuel shut-off that the fuel-air ratio in the test section was unchanged by incoming air. The energy was then adjusted and tests were run until the minimum amount of energy that would cause ignition was determined. Three oscillograms were usually obtained at the minimum value, and the minimum ignition energy reported is the average of the three tests. In a few cases, more than three readings were taken in order to obtain a satisfactory average.

RESULTS AND DISCUSSION

The effects of gas-stream velocity, size of turbulence promoter, and distance from the promoter plate to the electrodes on minimum ignition energy are shown in figure 2. With all test configurations, the minimum spark-ignition energy increased with an increase in stream velocity. The curves show that for constant velocity the ignition energy increased with wire size of the promoter and decreased with distance from the promoter. The effect of turbulence promoters on ignition energy is more pronounced at the higher velocities. The data show that, at a gas-stream velocity of 250 feet per second, the introduction of the 0.105-inch wire-diameter screens increased the required energy by a factor of 3. The curve representing no turbulence promoter crossed the 0.006-inch wire-diameter promoter curves; however, this cross-over may not be considered significant since the difference between the curves lies almost within the expected deviation. The deviation from the average energy values was about ±8 percent.

The curves of figure 2 tend to converge at the lower velocities and must meet when the velocity is zero. Interpolation of data from reference 3 gives an energy value of about 7.5 millijoules for a short-duration spark under zero-velocity conditions. The zero-velocity energy value with the present long-duration spark may be expected to be slightly lower than 7.5 millijoules.

The intensity of isotropic turbulence increases with velocity and wire size of the turbulence promoter and decreases with distance from the promoter (reference 4). Analysis of the data presented in figure 2 thus indicates that the minimum ignition energy increased with those factors that give an increased intensity of turbulence. It would be desirable to correlate ignition energy with stream velocity, intensity, and possibly, scale of turbulence. Measurements of the spectrum of turbulence in the longitudinal direction with a hot-wire anemometer revealed the presence of pulsations from the exhaust facility and duct resonance, which caused the turbulence spectrum to deviate from the characteristic isotropic spectrum. Equipment was not available for turbulence measurements in the lateral direction. Since the dissipation of the spark energy depends upon diffusion in both directions, it is necessary that both directions be investigated. Hence, the correlation of energy with fundamental turbulence parameters was not attempted in the present investigation.

SUMMARY OF RESULTS

The following results were obtained in an investigation of the effect of gas-stream turbulence on the minimum spark-ignition energy required to ignite a 0.0835 (by weight) propane-air mixture at a temperature of 80° F and a pressure of 5 inches of mercury absolute using a 500-microsecond-duration spark:

1. The required spark-ignition energy increased with wire size of the turbulence promoter and with gas velocity and decreased with distance from the promoter to the spark electrodes. The required ignition energy therefore increased with those factors that are reported to result in increased intensity of turbulence.

2. At a velocity of 250 feet per second, three times more energy was required with the 0.105-inch wire-diameter promoter than with no promoter.

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REFERENCES

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2. Swett, Clyde C., Jr.: Spark Ignition of Flowing Gases. II - Effect of Electrode Parameters on Energy Required to Ignite a Propane-Air Mixture. NACA RM E51J12, 1951.

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4. Dryden, Hugh L.: A Review of the Statistical Theory of Turbulence. Quart. Appl. Math., vol. 1, no. 1, April 1943, pp. 7-42.

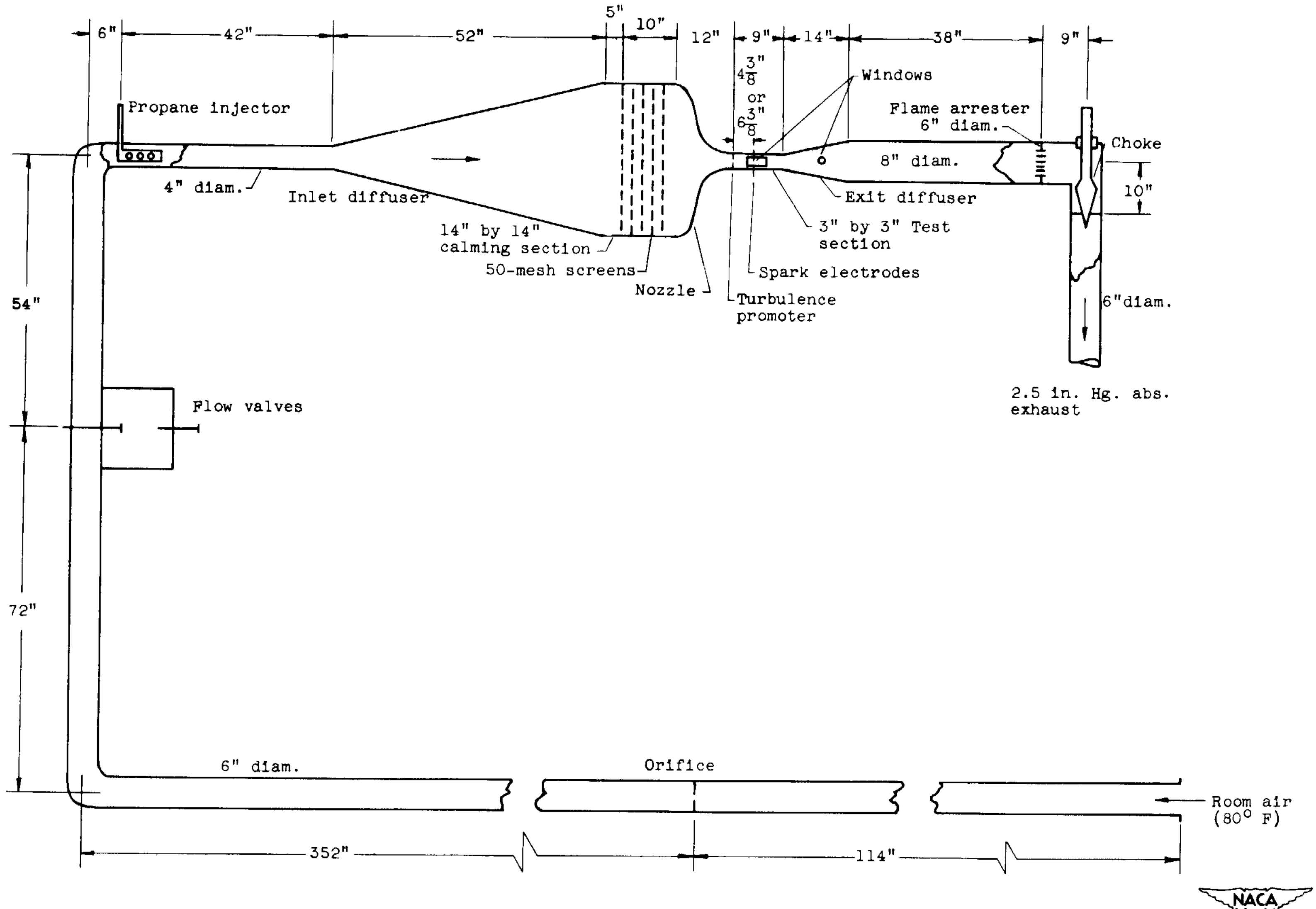

Figure 1. - Apparatus used for determining effect of turbulence promoter on spark-ignition energy.

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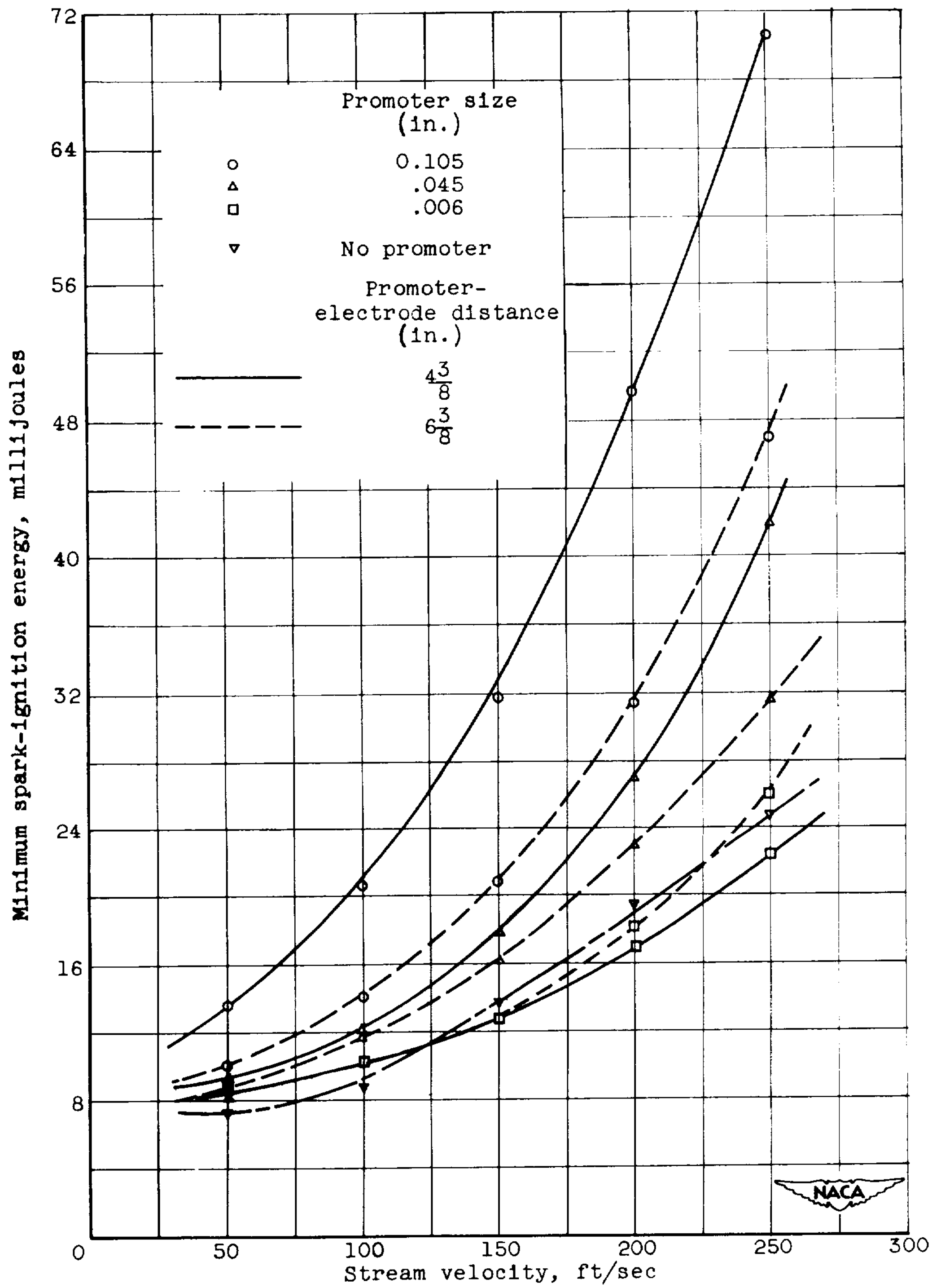

Figure 2. - Effect of stream velocity, promoter size, and distance from promoter to spark electrodes on minimum spark-ignition energy of propane-air mixture. Pressure, 5 inches mercury absolute; temperature, 80° F; fuel-air ratio, 0.0835.

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